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WATERJET PROCESSES FOR COATING REMOVAL

by

Fletcher Burgess
Steve Cosby
Materials & Processes Department
USBI, Co. P.O. Box 1900
Huntsville, AL 35807

David Hoppe
National Aeronautics and Space Administration
Materials & Processes Laboratory
Marshall Space Flight Center
Huntsville Al. 35812

ABSTRACT

USBI and NASA have been testing and investigating the use of high pressure water for coating removal for approximately the past 12 years at the Automated TPS(Thermal Protection System - ablative materials used for thermal protection during ascent and descent of the solid rocket boosters) Removal Facility located in the Productivity Enhancement Complex at Marshall Space Flight Center. Originally the task was to develop and automate the removal process and transfer the technology to a production facility at Kennedy Space Center. Since that time more and more applications and support roles for the waterjet technology have been realized. The facility has become a vital part of development activities ongoing at MSFC. It supports the development of environmentally compliant insulations, sealants, and coatings. It also supports bonding programs, test motors, and pressure vessels. The most recent role of the cell is supporting Thiokol Corporation's solid rocket motor program in the development of waterjet degreasing and paint stripping methods. Currently vapor degreasing methods use 500,000 lbs. of ozone depleting chemicals per year. This paper describes the major cell equipment, test methods practiced, and coatings that have been removed.

Introduction

The use of high pressure water as a means of coatings removal was used in the late 70's to refurbish the Solid Rocket Boosters (SRB) used in the space shuttle program. After recovery of the SRB's following a shuttle launch the TPS is removed from the booster components and prepared for future flights. Until this process was automated, it was a manual operation where personnel wearing protective suits and using high pressure waterjet wands would spend countless hours stripping the TPS. The results were acceptable but it was a very tiresome, tedious, and personally hazardous task.

USBI and NASA jointly developed a system to automate and optimize the TPS removal process using robotics. This system removed personnel from the hazardous environment and reduced the SRB processing time due to the precision stripping the automated TPS removal system is capable of delivering. Through emperical testing, the optimum waterjet stripping parameters for each TPS material were determined. All the testing and developmental work was done at MSFC in the Productivity Enhancement Complex and then the technology was transferred to Kennedy Space Center in Florida where it is currently used in the production facility.

Equipment

Robot - A Cincinnati Milacron HT^{3}™ Industrial hydraulic six axes pedestal mounted robot. Five axes are actuator driven and one is cylinder driven, all axes are controlled by servo valves. The normal hydraulic operating pressure is 2250 psi. The robot is mounted on a lift table that provides an extra 4 foot of travel on the Z axis. All axes are fed with with a low positive air pressure to prevent water intrusion into the actuator units and control boxes. The robot is capable of a 200 pound payload, this is necessary with the back thrust created by the high pressure water at high flow rates.

Computer - All system equipment interfaces with a Digital Equipment Corporation 11/73+. An Industrial Processor allows for discrete I/O, D/A and A/D interfaces. The turntable and robot interface through RS-232 communications.

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Pumps - The cell contains three pumping systems. The first system is a Hammelmann HDP650. As its model number implies it has a driving output capability of 650 horse power. The HDP650 has five 30 mm cylinders and can operate up to 2100 rpm's. The pump can deliver pressures up to 20,000 psi at a flow rate of 32 gallons per minute. The second system is a Hammelmann HDP334. The HDP334 has three 25 mm cylinders and with a 450 horse power output capability can deliver 36,000 psi at a flow rate of 12 gallons per minute. The third pumping system is a Flow Systems Model 11X intensifier. It is capable of delivering ultra high pressures up to 55,000 psi at flow rates up to 1.25 gallons per minute. The Flow Systems Waternife pump is used strictly for cutting processes and not coatings removal. The Waternife is capable of cutting all types of metals and composites without thermal distortion or delamination.

Frequency Drive - An Allen Bradley 1352 frequency drive is used to drive the 500 horsepower motors that drive the Hammelmann pumps from zero up to their maximum outputs of 20ksi or 36ksi. Only one pumping system can be operated at a time depending on which is selected at the frequency drive console.

Diversion Valves - Three Autoclave Engineering electrically controlled hydraulic operated valves are used to divert the high pressure water to the desired stripping nozzle. Up to three nozzles can be run at once but normal operation is done with either one single stream nozzle or a rotary nozzle. The third valve is normally used as a dump valve to divert the water during system setup or dump the pressure if an emergency situation should arise. The diversion valves are only used with the 20ksi pumping system.

Turntable - The turntable is 12.5 foot in diameter and is equipped with outrigger attachments and supporting hardware that allows it to accomodate each SRB component. This includes the nose cap, frustrum, forward skirt, and aft skirt. The table is capable of speeds up to six revolutions per minute. The table platen floats on air bearings which are capable of handling heavy loads. The entire table is also mounted on air bearings which allows the table to be easily positioned anywhere in the spray cell. It is also equipped with jacks, wheels, and a tow bar so it can be completely removed from the spray cell or used for transporting hardware short distances.

Nozzles - A variety of different styles and types of nozzles have been tested. The most efficient and effective nozzles were found to be the single stream stripping nozzles developed by USBI and rotating nozzles developed by Hammelmann Corp. and Flow International Corp. The single stream Full Tapered Stripping(FTS) nozzles were developed early in the program after it was found that off the shelf nozzles exhibited wear after several hours of operation at pressures up to 20,000 psi. The FTS nozzles were designed and patented by Messrs. Steve Cosby, a senior USBI Process Engineer; and Robert M. Rice, a senior Robotics Engineer (currently working with Pratt & Whitney Waterjet Systems). The FTS nozzles are easily installed in a 3/4" Autoclave Slimline fitting and will also readily adapt to a mixing chamber that was designed along with the FTS nozzles that allows abrasives such as crushed walnut shells and plastic media to be injected into the high pressure water stream to improve stripping rates. The mixing chamber is designed such that the abrasive is pulled in due to the venturi effect created by the water passing through the chamber.

The Hammelmann twin jet rotating nozzle is the most effective at pressures up to 20,000 psi. The twin jet nozzle is capable of speeds up to 1200 rpm. The two orifices are configured so that the back force of the water itself causes the nozzle rotation - the higher the pressure and flow through the nozzle, the faster the nozzle rotation. The twin jet nozzle also has an adjustable braking system that gives the user a limited control over the speed of the nozzle. The braking system uses an internal magnet, the more the magnet is engaged, the slower the rotational speed.

Hammelmann also designed two rotating nozzles that are used with the 36,000 psi pumping system. One will accomodate four orifices that are positioned at radii of 32.5mm, 37.5mm, 42.5mm, and 47.5mm. The other nozzle will accomodate fourteen orifices and they are located 2.5mm apart starting at a radius of 15mm and ending at a radius 47.5mm. The two nozzles are interchangeable with the same hydraulic drive unit. The drive system is capable of rotating the nozzles up to 2300 rpm. The orifices are also interchangeable and are sized to achieve the desired flow rate. The orifices mount at a 90 degree angle to the face of the nozzle.

Test Methodology

There are a number of hydro stripping parameters that play a role in coating removal rates. These parameters include water pressure, flow rate, stand off distance, stripping velocity, attack angle, sweep angle of attack, and with the rotary nozzles include orifice size and placement as well as the nozzle rotational speed. It was found that by controlling these parameters a piece of hardware could be stripped to selected levels. The insulation could be removed leaving the topcoat of paint undamaged, the paint could be removed leaving the primer intact, and finally the primer could be removed leaving the bare substrate.

Most of the tests are conducted on flat 24" x 24" test panels with the coating to be tested applied at the nominal thickness. The test panels can be mounted on support structures that are mounted on the turntable. The robot end effector is configured with the nozzle to be tested and the robot is "taught" the motions needed to conduct the desired testing. Normally a "rough and dirty" test is done to determine what range of the variable parameters will be tested. Once test runs have been made with the range of test parameters, each test pass or panel is assessed and the level, width, and rate of coating removal are determined. Test results are used to determine the optimum coating removal parameters.

The major focus of testing is identifying the orifice diameter that maximizes the available energy, i.e., the nozzle that removes the coating most effectively with the available pressures and flows.

After the installation of the Hammelmann 36ksi pumping system and the multiple orifice nozzles were tested it was found that the orifice size and placement on the nozzle were very critical in order to achieve an even energy distribution throughout the stripping width of the nozzle. Random orifice selection normally yielded visible energy bands on the substrate where there was obviously concentrated levels of pressure and flow. To improve the energy distribution, theoretical flow rates/orifice distance traveled, based on the orifice location on the nozzle(radius) were determined. The orifices were sized so that there is an equal flow of water per orifice distance traveled regardless of the orifice location on the nozzle. In other words, if the orifice located at a radius of 15mm flowed one gpm/revolution of the nozzle which equates to:

@r = 15mm

$$circumference = \pi d = \pi 30mm = 94.25mm$$

@ 1rpm

$$\frac{1gpm}{94.25mm} = .0106 gpm/mm$$

then the orifice located at a radius of 30mm would be sized so that its flow would be equal to .0106 gpm/mm traveled by the orifice.

Example:

$$circumference = \pi d = \pi 60mm = 188.49mm$$

$$\frac{xgpm}{188.49mm} = .0106 gpm/mm$$

$$x = 1.99 gpm$$

This approach was used to determine orifice size regardless of how many orifices were used, whether it be four or fourteen. Along with equalizing the flow per distance the orifice traveled, the nozzle rotational speed and the stripping velocity were very dependent on each other and were critical stripping parameters to determine. With the help of a user friendly computer simulation program developed by Mr. David Hoppe (NASA Engineer) the optimum rotational velocity and robot stripping velocity could be determined to achieve the most efficient coverage of the stripping width. The computer program allowed the desired orifices, the rotational speed, and the stripping velocity to be entered and a graphic display is generated showing the coverage. The program also provides a quantitative analysis of the coverage by counting the number of pixels on the computer monitor not hit by the orifices selected. It was also found that the direction of travel across the test panel whether it be left to right or vice versa also played a role in the coverage and removal rates.

Coatings Removed

Over the years a number of insulations, adhesives, paints, and coatings have been stripped at the MSFC Automated TPS Removal Facility. The following matrix list most of those along with a brief description of the coating, approximate stripping rates, and the nozzles used. Most of the coatings were applied to aluminum substrates, either 2219-T87, 6061, or 7075 Alclad. The rubber insulations and propellants have been removed from D6AC steel and NBR has been removed from a filament wound case - shallow stripping angles were used to prevent delamination of the case from occuring. The high pressure water does have the capability to damage any surface if steps are not taken to ensure the waterjet does not dwell in the same spot too long.

Coating	Description	Nozzle	Removal Rate
1/4" MSA-1	SRB thermal protection insulation	rotary&FTS	57-75 in^2/sec
1/2" MSA-2	SRB thermal protection insulation	rotary&FTS	30-40 in^2/sec
1/8"-1/4" MSA-3	SRB thermal protection insulation	rotary	52-61 in^2/sec
3/8"-1" K5NA	SRB closeout material	rotary	4-6 in^2/sec
3/8"-1" MTA-2	SRB closeout material	rotary&FTS	16-30 in^2/sec
1/4"&1/2" CORK	SRB thermal protection & closeout material	rotary&FTS	11-14 in^2/sec
3/8"-1" BTA	SRB closeout material	FTS	7-15 in^2/sec

Coating	Description	Nozzle	Removal Rate
1/8"-1/4" USI	SRB & Titan IV thermal protection insulation	rotary	8-13 in^2/sec
1/8"-1/4" MCC-1	SRB & Titan IV thermal protection insulation	rotary	18-26 in^2/sec
1"-1.5" SOFI	External Tank insulation	rotary	60-70 in^2/sec
1.5" INSTAFOAM	SRB thermal protection insulation	rotary	80 in^2/sec
1/32" ZINC COATING	Thrust Vector Control Cover corrosion protection	rotary	5-7 in^2/sec
2"-4" NBR	MNASA motor insulation	FTS	.3-.5 in^2/sec
2"-3" INERT PROPELLANT	Hybrid motor propellant	FTS	removed in sections
HYSOL 901	test sample bonding adhesive	rotary	*10 in^2/sec
HYSOL 934	test sample bonding adhesive	rotary	*10 in^2/sec
HYSOL 913	test sample bonding adhesive	rotary	*6-7 in^2/sec
HYSOL 946	test sample bonding adhesive	rotary	*10-17 in^2/sec
HYSOL 615	test sample bonding adhesive	rotary	*10 in^2/sec
HYSOL 9689	test sample bonding adhesive	rotary	*10 in^2/sec
HYSOL 608	test sample bonding adhesive	rotary	*10 in^2/sec
3M 2216A/B GRAY & TRANSLUCENT	test sample bonding adhesive and component of MSA1&2, BTA, USI, & MCC1	rotary	*10 in^2/sec
3M CA5	test sample bonding adhesive	rotary	*10 in^2/sec
3M CA9	test sample bonding adhesive	rotary	*10 in^2/sec
LOCTITE 410	test sample bonding adhesive	rotary	*10 in^2/sec
CREST 212	test sample bonding adhesive	rotary	*10 in^2/sec
RTV 133	sealant	rotary&FTS	5.5 in^2/sec
PRC 1770	high temperature sealant	rotary	5.5 in^2/sec
PRC 1422	high temperature sealant	rotary	5.5 in^2/sec
URETHABOND 3015	TPS topcoat	rotary&FTS	removed with TPS
HYPALON HFR2200	TPS topcoat	rotary&FTS	removed with TPS

Coating	Description	Nozzle	Removal Rate
AKZO PAINT & PRIMER	Aluminum substrate corrosion preventive	rotary	*10 in^2/sec
DEFT PAINT & PRIMER	Aluminum substrate corrosion preventive	rotary	*10-12 in^2/sec
CONOCO HD2 GREASE	solid rocket motor case corrosion preventive	rotary	*52 in^2/sec
SHELL DIALA OIL	solid rocket motor static pressure test	rotary	*80-90 in^2/sec
MAGNAFLUX MAGNAGLOW 20B & WA4	magnetic particle solution and rinse used for motor case inspection	rotary	*80-90 in^2/sec
RUSTOLEUM PAINT & PRIMER	D6AC steel motor case corrosion preventive	rotary	*10-12 in^2/sec
CHEMLOK 205/233	motor case preparation before insulation bonding	rotary	*9-10 in^2/sec
CHEMLOK 205/220	motor case preparation before insulation bonding	rotary	*7-8 in^2/sec
CHEMLOK 205/236A	motor case preparation before insulation bonding	rotary	*12-13 in^2/sec

* These represent removal rates that were achieved with the 36ksi pumping system using either the Hammelmann or Flow International nozzles. All other rates were accomplished with the 20ksi system.

Current Investigations

Testing is being done with multiple orifice rotating nozzles to improve stripping rates. Orifice size, design, and location on the nozzle are parameters that are being investigated. Several orifice designs by Hammmelmann have gone through some limited testing. The first is a sapphire orifice, which has the same design as orifices used with the waterjet cuttting system, but require a sealing lens when installed in the nozzle. The sapphire nozzles have an efficiency rating of 63%. Other orifices tested are stainless steel and much more easily installed and aligned in the nozzle(no sealing lens). The stainless steel nozzles have an efficiency rating of 92%. The higher efficiency orifices keep the water stream collimated longer allowing larger stand off distances and improved stripping rates. Collimation is critical for nozzle efficiency, therefore other nozzles with collimated channels feeding the orifices are being investigated. The more laminar the flow when it reaches the orifice, the longer the waterjet stream will stay collimated. Efficient nozzles are the key to coating removal and will continue to be a focus of the Automated TPS Removal Facility.